AN ESTIMATION OF SAGE II CLOUD LONGWAVE RADIATIVE FORCING BETWEEN 1985 AND 1998: PRELIMINARY RESULTS

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ABSTRACT

The present study investigates the cloud longwave radiative forcing (CLRF) based on cloud observations of the Stratospheric Aerosol and Gas Experiment (SAGE) II between November 1984 and December 1998, along with the meteorological information provided to the SAGE II data processing team by the National Center for Environment Prediction (NCEP). The preliminary results suggest a range of the global mean CLRF of about –34 to –68 W/m^2 and a range of increasing CLRF trend of about 0.5 to 1.0 W/m^2/decade for the 15-year period of the SAGE II observation.

1. INTRODUCTION

The presence of clouds affects the heat balance of the Earth-atmosphere system through their interaction with the outgoing longwave and incoming shortwave radiation. The impact of long-term changes in cloud properties on the Earth climate has been a subject of increasing concern in recent years. The primary objective of this study is to conduct a model estimation of the cloud longwave radiative forcing (CLRF) by using cloud information between December 1984 and November 1998 derived from the observations of the Stratospheric Aerosol and Gas Experiment (SAGE) II and the temperature data from the National Center for Environment Prediction (NCEP), with particular focus on the global trend of the CLRF.

2. RELEVANT FEATURES OF SAGE II

The SAGE II instrument is a 7-channel Sun-photometer aboard the Earth Radiation Budget Satellite (ERBS) launched in October 1985. These seven channels are centered at 0.385-, 0.448-, 0.453-, 0.525-, 0.600-, 0.940-, and 1.02-μm wavelengths. The limb atmospheric transmission data obtained by using the solar occultation technique during spacescraft sunrises and sunsets are then used to derive ozone, nitrogen dioxide, and water vapor vertical distributions, as well as the particulate extinction coefficient profile at 0.385, 0.453, 0.525, and 1.02 μm, with a 1-km vertical resolution. The field of view of the instrument is specified by a coverage of 0.5 km (in the vertical) by 2.5 km (in the horizontal) at the tangent point [Mauldin et al., 1985; McCormick, 1987]. Chu et al. [1989] have discussed the data inversion algorithm in detail. Because the wavelength dependence of the molecular scattering is heavily toward shorter wavelengths, only the measurement made at the 1.02-μm particulate extinction coefficient is capable of reaching the Earth surface.

Satellite remote sensing using the solar occultation technique is extremely sensitive to the presence of clouds, because of the relatively long atmospheric limb tangent viewing path in contrast to the vertical path length of a nadir viewing satellite instrument. The SAGE II observations have been used to infer the global distributions of two general groups of clouds, namely, opaque and subvisual clouds [Wang et al., 1996]. The presence of opaque clouds terminates the profiling of the SAGE II instrument [McCormick et al., 1979]. Therefore, information on opaque cloud occurrence is imbedded implicitly in the SAGE II measurements. In the case of the SAGE II subvisual clouds, their extinction coefficients are within the measurement range of the SAGE II instrument. The capability of the SAGE II instrument in measuring subvisual clouds can be easily understood as aerosols and clouds are interrelated through microphysical processes [Wang et al., 1994].

When the atmosphere is not heavily influenced by volcanic aerosols, the termination of the profile of the SAGE II extinction coefficient at 1.02 μm above the surface is clearly an indication of the presence of opaque cloud. Therefore, the satellite solar occultation sampling event over a given area and time period would generally be reduced as the altitude decreases in the troposphere. According to the cirrus cloud classification of Sassen and Cho [1992], the SAGE II opaque clouds generally include all types of clouds, except optically thin subvisual clouds [Wang et al., 1996]. Wang et al. [1995] have presented a method that can be used to derive the occurrence of the SAGE II opaque clouds as a function of altitude on a statistical basis. The identification of subvisual clouds from the SAGE II observations is a more involved process. Perhaps, the most reliable method for identification of subvisual clouds to date is the two-wavelength method developed by Kent et al. [1993]. The seasonal distribution of the SAGE II extinction coefficients at 0.525 and 1.02 μm at a given altitude over a certain geographic region reveals generally two distinct data groups corresponding separately to aerosols and clouds, with the latter showing lack of variation of extinction coefficient with wavelength.

3. DATA ANALYSIS

The SAGE II measurements (version v5) from November 1984 to November 1998 are grouped into fifteen 10-degree latitudinal bins between 75°S and 75°N on a seasonal basis for determining cloud time series data sets. Because the heavy loading of volcanic aerosols from the massive June 1991 Pinatubo eruption makes cloud identification extremely difficult, the SAGE II observations obtained between June 1991 and November 1993 are excluded from the present study. To cover the entire troposphere, the seasonal SAGE II cloud data below 20-km altitude are examined for linear trend at SAGE II altitudes for each of the latitudinal bins. The corresponding NCEP temperature data are analyzed in a similar manner. To examine the time series SAGE II cloud and NCEP temperature data sets, we use a simple linear regression analysis of the form

$$y(t) = a_0 + a_1 \times t + \varepsilon \qquad (1)$$

where t represents time, y the time series observations, a_0 a constant term, a_1 the slope corresponding to the linear trend of the time series data set, and ε the residual error.

To estimate the CLRF, we employ Ramanathan's [1977] model

$$F = C \times \varepsilon \times A \times (T_c - T_g) \qquad (2)$$

where F is the cloud longwave radiative forcing, C is the empirical model coefficient, ε the cloud emissivity, A the cloud occurrence frequency, T_C the cloud temperature, and T_g the surface temperature. The analysis of Ramanathan [1977] suggests a value of 1.65 W/m^2/K for the coefficient C. We have examined the empirical model based on the more recent cloud radiative transfer studies of Fu and Liou [1993] and Kiehl [1993]. The results of this examination are given in Fig. 1. As we can see, the analyses based on the model of Fu and Liou [1993] and Kiehl [1993] consistently yield a higher model coefficient C value of 2.24 W/m^2/K. We have used this new coefficient in the present study.

Because the SAGE II observations contain no information on cloud emissivity, we introduce 0.5 and 1 as

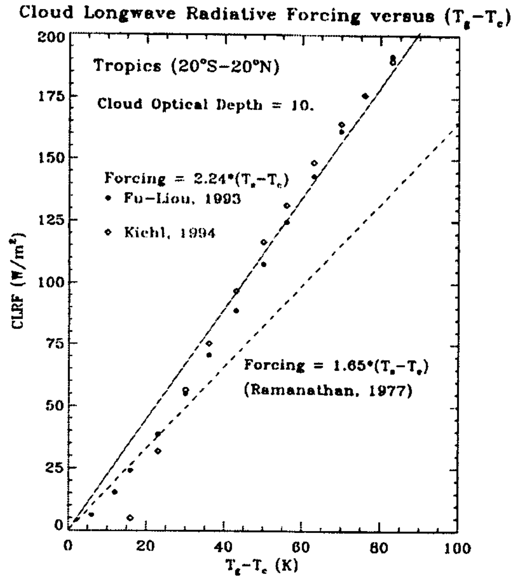

Fig. 1. Cloud longwave radiative forcing versus temperature difference between the surface and cloud.

the two extremes of the cloud emissivity for the CLRF estimation. The model calculations are carried out at each of the SAGE II altitudes for each latitudinal bin. We then carry out the vertical integration of the derived F to determine the total CLRF as a function of latitude. Because of the frequent occurrence of clouds with a thickness greater than the 1-km SAGE II vertical resolution and of multilayer clouds, a correction factor of 0.5 is applied to the vertically integrated CLRF results. This correction factor is determined from a comparison of the vertically integrated cloud occurrence frequency according to the SAGE II 1-km data set with the cloud occurrence frequency determined by treating the troposphere as a single layer.

4. RESULTS

The preliminary results of the derived multiyear mean CLRF as a function of latitude are displayed in Fig. 2. The negative forcing indicates reduced outgoing longwave radiation due to presence of clouds as compared to the clear sky radiation. Because cloud occurrence is at a maximum in the tropics, the CLRF peaks there as expected. The magnitude of CLRF in the subtropical regions is relatively smaller than that in the tropics, due to much less cloud presence [Wang et al., 1996]. The magnitude of CLRF then increases slightly toward high latitudes. The present study further suggests a range of the area-weighted global mean CLRF between –34 and –68 (W/m^2). The preliminary results of the linear trend are given in Fig. 3. The CLRF trend generally reveals positive values in the tropical regions and at high latitudes and negative values in the subtropics. The estimated range of the area-weighted global CLRF trend is between about 0.5 and 1.0 W/m^2/decade

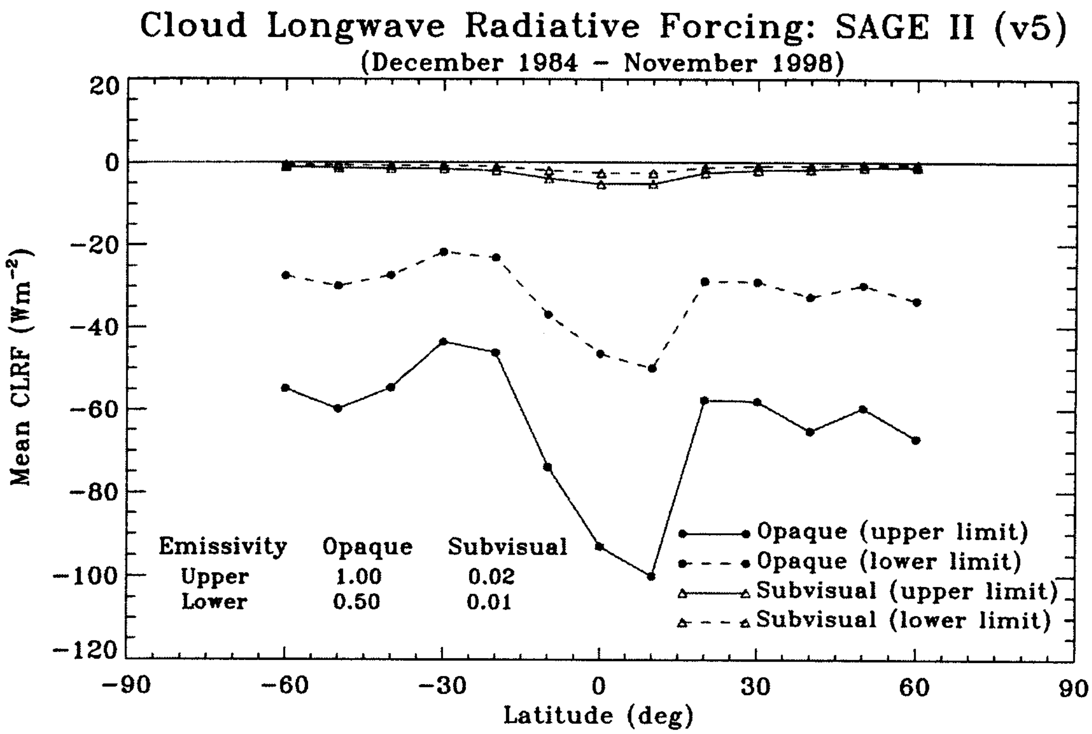

Fig. 2. Multiyear (1985–1998) mean CLRF (W/m^2) as a function of latitude.

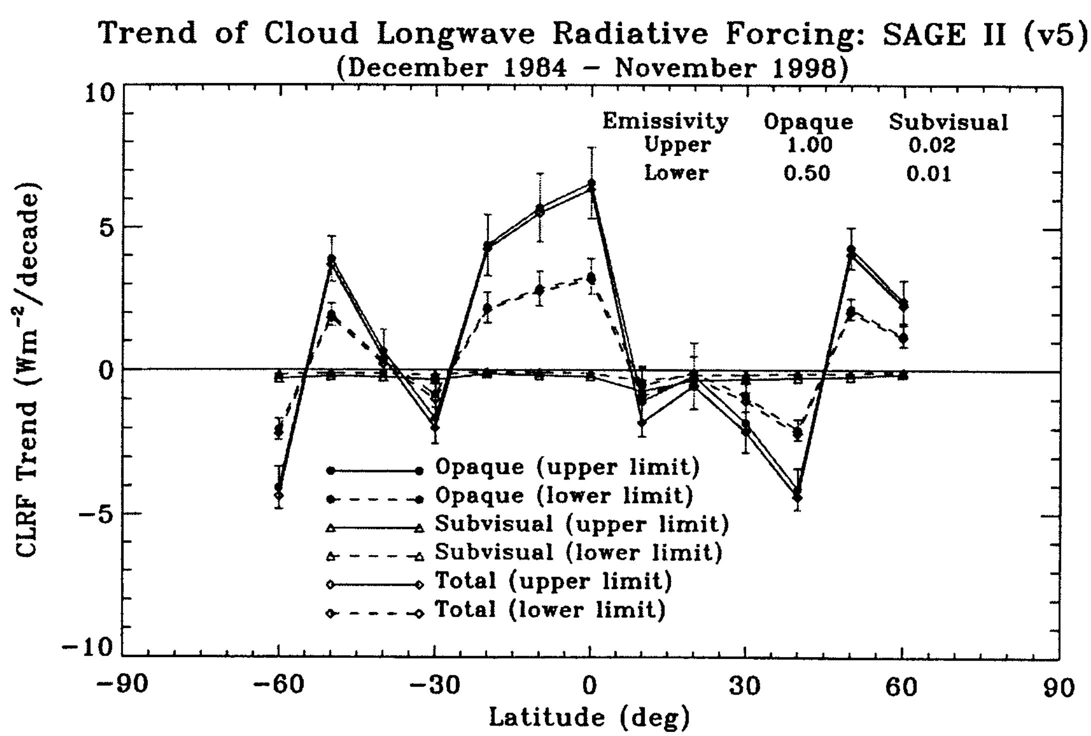

Fig. 3. Trend (1985–1998) of CLRF (W/m^2/decade) as a function of latitude.

from December 1984 to November 1998. A summary of the preliminary results is presented in Table 1.

Table 1. Range of SAGE II Global CLRF (1985–1998)

	Mean (W/m^2)	Trend (W/m^2/decade)
Lower limit	–34.0 (0.05)	0.52 (0.15)
Upper limit	–68.1 (0.10)	1.04 (0.29)

• Number in bracket indicates standard deviation.

5. CONCLUSIONS AND REMARKS

The present study examines the time series of the CLRF based on SAGE II cloud observations and the NCEP meteorological data from December 1984 to November 1998. It should be mentioned that the derived SAGE II opaque cloud occurrence assumes the most important effect on CLRF. Because the SAGE II 1.02-μm measurement is terminated at about an optical depth of 0.02 to 0.03, it is quite possible that some portions of the derived SAGE II opaque cloud data are not truly optically thick in terms of longwave radiation. Unfortunately, the SAGE II instrument does not provide such detailed information on the cloud optical depth. To estimate CLRF, we have examined the possible boundary of the CLRF by using 0.5 and 1 as the range of the cloud emisssivity. The preliminary results of the estimated range of the global area-weighted mean and trend are –34 to –68 W/m^2 and 0.5 to 1.0 W/m^2/decade, respectively. Note, the positive CLRF trend corresponds to a decline in the reduction of the outgoing longwave radiation associated with cloud presence. Because the CLRF depends on the temperature contrast between the cloud and the surface, cloud changes in the coldest regions near the tropopause assume the most important impact on the trend of CLRF. It should be mentioned that CLRF depends on cloud properties, i.e., cloud amount and emissivity, as well as the temperature contrast between cloud and the surface. Thus, to further understand the CLRF trend, one also needs to examine the effect of the time series of these relevant components on the CLRF separately. Such a study is in progress and will be reported subsequently.

The latitudinal zoning pattern of the positive and negative CLRF trend is very interesting and significant. This pattern appears to be related to the latitudinal cloud distribution, hence to the tropical large scale meridional circulation. A very important question is then whether changes in the tropospheric circulation might have happened during the data period of the present study. Further investigations using different cloud data sets as well as general circulation models are highly desirable.

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